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Study on Antiwear and Repairing Performances about Mass of Nano-Copper Lubricating Additives to 45 Steel

X. L Wang[a]*, Y. L. Yin[a], G. N. Zhang[a], W. Y. Wang[a], K. K. Zhao[a]

[a] *Science and Technology on Remanufacturing Laboratory, Academy of Armored Forces Engineering, Beijing 100072, China*

Abstract

Nano-copper usually serve for lubricating additives in tribology field. The antiwear and reducing friction performances both basic lubrication oil and basic lubrication oil with nano-copper in different mass were tested by friction wear test machine. The morphologies and the main elements of worn surfaces were analyzed by SEM. The results indicated that nano-copper could improve tribology performances of basic lubrication oil. Comparing with base lubrication oil, the mass is 0.15% of nano-copper, the friction coefficient and the worn trace width can be reduced 34% and 32% respectively. Nano-copper can form self-repairing film in lubrication oil which availably separates the friction materials in friction process. Therefore, nano-copper has wonderful antiwear, reducing friction and self-repairing performances. And the function mechanism of Cu nanoparticles is studied in the paper.

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Keywords: Nano-copper; Solid lubricant additives; Tribological properties

1. Introduction

Since nano materials have been discovered in the 1980s, home and abroad researchers have observed that nano materials possessed excellent anti-wear and friction-reducing properties in lubrication oils, and then the field was studied, utilized and exploited by some researchers(Kolo dziejczyk, L. et al.,2007;ZHANG, Z. F. et al.,1998;DONG, J. X., HU, Z S.,1998). The nano-copper has perfect tribology performances especially in reducing friction coefficient, enhancing wear-resisting property; improving materials compactness and in-situ surface modification technology, because of its low shear strength and strong diffusibility(ZHANG, L. D., MOU, J.,2001;LIU et al.,2005;WANG, X. L. et al.,2005).

In recent years, numerous studies have been carried out on the effect of Cu nanoparticles as lubricant

* *Emaill*: wxli_bh@163.com

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additive on friction and wear. Hisakado et al.(Hisakado et al.,1983) reported that nano-copper had excellent resisting extreme pressure ability in 1983. Tarasov et al.(TARASO et al.,2002) discovered that the anti-wear and friction-reducing properties of friction pairs were improved obviously through blending nano-copper into SAE30 engine oils. XIA Yanqiu(XIA, Y. Q. et al.,1999), Lan Zhou Institute of Chemical Physics, carried out friction and wear experiments by adding 10-15 nm nano-copper lubricating additives into paraffin lube oils, and he reported that it could reduce friction coefficient and the diameter of worn spots. The similar results and conclusions were obtained in the National Key Laboratory for Remanufacturing, and nano-copper compound additives were developed. Due to outstanding tribological and anti-wear properties, together with environment-friendly and cheap characteristics, it has been assigned for one of the top choice additives for army vehicles and equipments(SHI, P. J. et al.,2008;HE, H. L. et al.,2010). In the paper, tribology performances and repairing performances of nano-copper lubricating additives to 45steel are studied.

2. Experimental

2.1. Properties test

The MM-200 friction and wear tester was employed to study friction-reduction and anti-wear abilities of nano-copper lubricating additives. Friction pairs are ring specimen and clumpy specimen, which are 40 ㎜×10 ㎜×Φ16 ㎜ and 30 ㎜×10 ㎜×Φ16 ㎜ respectively. Friction specimens are 45 steel and mechanical properties are shown in table 1. Mineral oil SN 650 by adding nano-copper lubricating additives made in our laboratory 0.1wt.%、0.15wt.%、0.175wt.%、0.5wt.% and 1.0wt.% was used as a lubricant for ring and block friction specimens. Other experimental conditions were: atmospheric environment, room temperature, step loading of 400N, rotational velocity of 200 r/min and test duration of 60 min.

Table 1 mechanics characteristics of 45 steel

Mechanics properits			
σb /MPa	HRC	δ /%	Ak /J · cm-2
750~780	50~51	15~20	50~80

2.2. Characterization Techniques

The QUANTA Scanning Electronic Microscope (SEM) was used for observing micro-phologies of worn surfaces lubricated with SN 650 oils and SN 650 oils containing 0.15 wt. % nano-coppers. Genesis Energy Dispersive Spectrometry (EDS) and XPS analysis with the PHI-5702 system were carried out to study element distributions and the chemical state of worn surfaces lubricated with SN 650 oils containing 0.15 wt. % nano-copper.

3. Results and discussion

3.1. Wear and Friction Properties Analysis

Relationship curves about mass of nano-copper with friction coefficient and wear trace width can be expressed as anti-wear and friction reducing properties of nano-copper lubricating additives. When the surface of clumpy specimen is polished, the result is shown in Fig. 1.

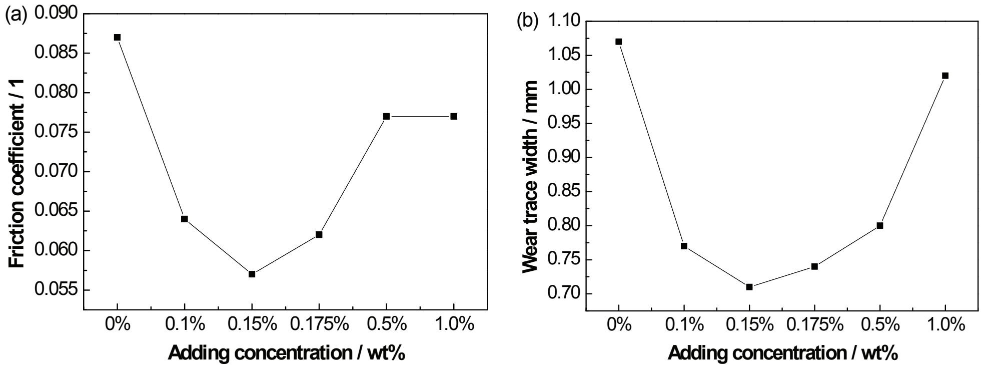

Fig.1 Relationship curve about mass of nano Cu with friction coefficient and wear trace width :(a) Friction coefficient size with adding mass of nano Cu; (b) The change of wear trace width with adding mass of nano Cu

Fig.1 shows the friction coefficient and the wear trace width under different lubricating conditions, showing that the friction and wear were reduced by blending Cu nanoparticles to SN 650 oil. It can be seen that the friction coefficient and the wear trace width presented a minimum, namely decreased before the concentration of 0.15 wt. % and then increased after that. The reason why the friction and the wear trace width increased may be that the lubricating film has been partly broken with the increasing Cu nanoparticles on friction surfaces. When the concentration of nano-copper lubricating additives is 0.15 wt.%, the friction coefficient and the wear trace width could be decreased by 34% and 32% respectively, as compared to the SN 650 oils without nano-copper lubricating additives, which showed that the best friction-reduction and antiwear property could be obtained when the concentration of nano-coppper additives is 0.15 wt.%. The reducing of the friction coefficient and the wear trace width demonstrates that nano-copper lubricating additives have excellent friction reduction and antiwear property on friction surfaces.

3.2. Morphology analysis on worn surfaces

SEM was utilized to observe morphologies of different degree of roughness of worn surfaces lubricated with SN 650 oils and SN 650 oils containing 0.15 wt. % nano-copper lubricating additives, respectively. The result was shown in Fig.2 and Fig.3. Obvious furrows and adhesions in sliding direction (see Fig.2a) could be found on worn surfaces lubricated with SN 650 oils, showing that the abrasive wear and adhesive wear were severe. Whereas the surface lubricated with SN 650 oils containing 0.15 wt.% nano-copper was very smooth without any scuffing (see Fig.2b)..

The optical microscope was applied to view morphologies of worn surfaces of Fig.2 (b) and the result was shown in Fig.4 (a). Worn surfaces were covered with the continuous or discontinuous yellow protective film lubricated with SN 650 oils containing nano-coppper additives. The direct contact of friction pairs was separated by the layer of the protective film in order to reduce friction and wear, which have energetic effect on the using life of friction pairs.

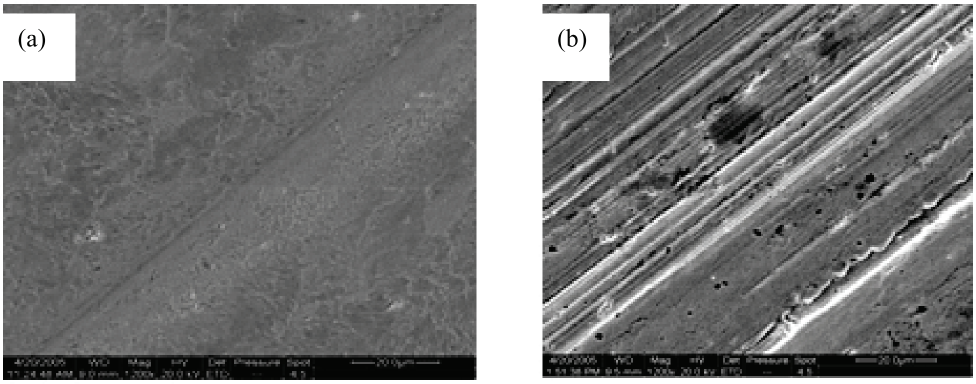

Fig.2 SEM images of different worn surfaces of the polished clumpy specimen:(a) 650SN ; (b) 650SN with n-Cu

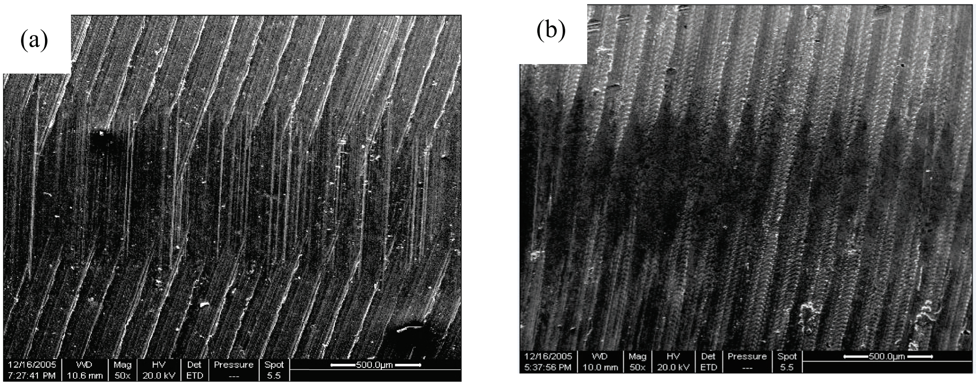

Fig.3 SEM images of worn surfaces of the machining part: (a) 650SN; (b) 650SN with n-Cu

Fig.4 (b) showed the EDS analysis results to yellow film. It could be seen that there existed the element of Fe from friction pairs besides a plenty of Cu, which demonstrated that the protective film was formed from nano-copper in SN 650 oils by rubbing on worn surfaces.

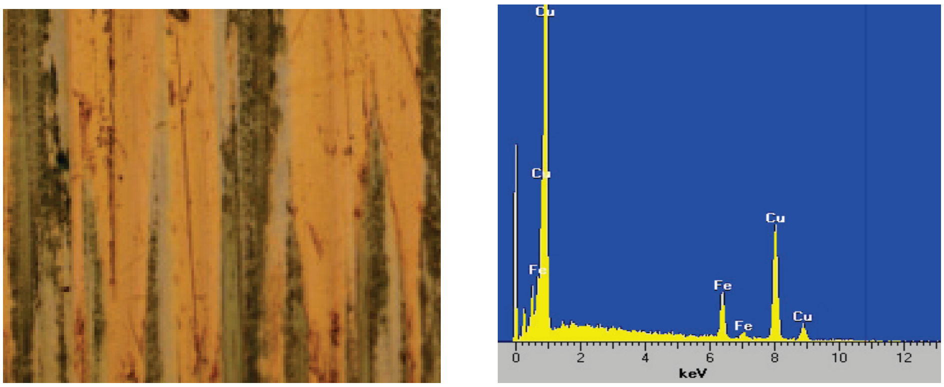

Fig.4 worn surface image and EDS analysis:(a)Wornsurface; (b) EDS analysis

The Fig. (5) showed the XPS analysis results to Fig. (4a). The peak position mainly at about 932.6 eV indicated metallic copper and Cu_2O, which demonstrated that a partof nano-copper lubricating additives in SN 650 oils existed as elementary substance Cu, and other part of nano-copper lubricating additives in SN 650 oils existed as Cu_2O. This showed that the yellow protective film was formed from the nano-copper through adsorption, permeation and tribochemistry reaction.

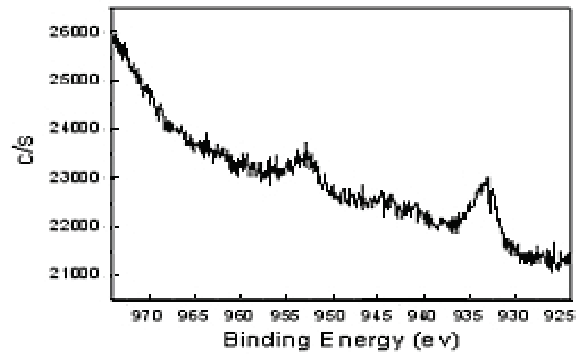

Fig.5 XPS curve of worn surface

4. Mechanism Analysis

Even any friction surfaces of parts are processed critically, surfaces of parts have rugged processing traces and plastic deformation traces under the microscope, showing the different degree of roughness of surfaces. When the two friction surfaces are contacted, the first contact must be the maximum height parts in the two surfaces, as shown in Fig.6(LI, G. Z.,2005).

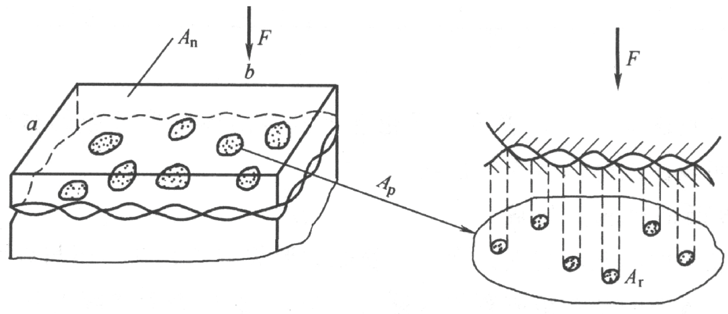

Fig.6 The contact diagram of friction surface

In Fig.6,

$$A_n = ab$$

$$A_P \approx (5 \sim 15)\% A_n$$

$$A_r \approx (0.01 \sim 0.1)\% A_n$$

The A_n is the nominal contact area; the A_p is the rough contact area; the A_r is the actual contact area and the F is load.

When the two uneven worn surfaces are contacted, the contact is discontinuous and asymmetrical. And the contact area is changed with load and rubbing.

From the Fig.2 and Fig 3(a), it can be seen that in lubricated with 650SN oil the plastic deformation and shear are arisen in the micro-bulge of actual contact. The surface film and oil film are ruptured, and the surface temperature is raised, so that the surface metal is soften or melt, which causes the contact point solid adhesion. Deep nicks are occurred in friction surfaces because the rubbing of worn surfaces is very severe.

Nano-copper lubricating additives have high activity and surface energy, and these performances are raised with the size of Cu nanoparticles decreased, as shown in table 2(ZHANG, L. D., MOU, J.,2001), so the nano-copper is added in lubricant oil. When high active nono-copper additives are arrived in friction surfaces and micro-pits of friction surfaces are filled through depositing or adsorbing nano-copper in friction surfaces. When the size of micro-pits in friction surfaces is nanoscale, micro-pits can be cured by the nano-copper, which is adsorbed in micro-pits or brought in micro-pits through rubbing, and the yellow protective film is formed, as shown in Fig. 4. So the friction capacity can be improved. But the elevated extent of friction capacity is different due to the degree of roughness of friction surfaces.

Table 2 the capability of nano-copper lubricating additives

particle size(nm)	ratio of surface atoms(%)	specific surface area ($m^2 \cdot g^{-1}$)	surface energy ($J \cdot mol^{-1}$)
100	--	6.6	5.9×10^2
10	20	66	5.9×10^3
1	99	660	5.9×10^4

Views of adsorption, permeation and tribochemistry reaction think that (1) nano-copper lubricating additives have fantastic diffusibility and self-diffusibility. The permeable formation and diffusion layer of friction properties are formed through nano-copper lubricating additives diffusing and permeating on the steel surfaces during rubbing. (2) The physical adsorption and tribochemistry reaction can be taken place on friction pairs surfaces during nano-copper lubricating additives rubbing in order to form physical adsorption layer and solid chemistry reaction film, which can be used for separating friction pairs(XU, B. S.,2004).

5. Conclusions

From the experiments and analysis performed, some conclusions can be made:

(1) Used as an additive for mineral oil, nano-copper presents excellent friction-reduction and anti-wear properties. The addiction of 0.15 wt. % nano-copper in SN 650 oil decreases the friction coefficient and wears trace width by 34% and 32%, respectively, as compared to the SN 650 without containing nano-copper.

(2) A lay of the protective film can be formed during the friction of the Cu nanoparticles, and friction pairs can be separated by the film in order to get excellent effect of anti-wear and friction-reduction.

(3) The tribological behavior of nano-copper additive is analyzed according to degree of roughness of worn surfaces, adsorption, permeation and tribochemistry reaction.

Acknowledgments

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